

# Review on the Extent of Acid Soil in Ethiopia, Its Impact and Management Methods

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## Abstract

Soil degradation is a global threat. Developing countries are more severely affected by soil degradation than developed countries. Ethiopia, one of the developing countries in eastern Africa, is highly threatened by soil degradation problems. Soil acidity is one of the main factors that limit and prevent profitable and sustained agricultural productivity in many parts of the world. The objective of this paper is to review the extent of acid soil distributions in Ethiopia, its impact on crop production and management practices. About 40.9% of the total arable land of Ethiopia is affected by soil acidity, from these 27.7% moderately to weak acids with pH 5.8-6.7 and 13.2% covered by strong to moderate acidic soils with pH less than 5.5. According to Ethio SIS, (2014) about 43% of the Ethiopian arable land is affected by soil acidity of these about 28.1% of soils in Ethiopia are dominated by strong acid soils (pH 4.1-5.5). Most of investigators confirmed that the two fundamental factors that limit the fertility of acid soils are: nutrient deficiencies, e.g. phosphorus (P), calcium (Ca) and magnesium (Mg) and the presence of phytotoxicity substances, e.g. soluble aluminium (Al) and manganese (Mn). To overcome these problems, different acid soil management has been implemented in the country. Thus many studies have been conducted with regards to Acid soil management which influences soil physical and chemical properties and crop yield directly or indirectly. Therefore, the aim of this seminar paper is to review different literature on the extent of acid soil in Ethiopia, its impacts on some selected chemical soil properties and management methods. Different studies showed that some soil chemical properties such as pH, Ava\_P, OC, CEC, Exchangeable Acidity (EA), Exchangeable bases (Ca, Mg, Na and K) and crop yields were improved in different agro ecologies by effects of liming and ISFM. Soil acidity problems also can be overcome by growing crop genotypes which are adapted to acid soil condition. Thus, for sustainable agricultural systems within small-scale farming in developing countries like Ethiopia, use of integrated soil fertility management, liming and crop varieties tolerant to Al toxicity are the mechanisms used for management of acid soils.

**Key note:** Acidity, Lime, ISFM, Acid tolerant crop varieties

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## 1. INTRODUCTION

Land degradation and low soil fertility are very common features of large parts of Sub-Saharan Africa (Vesterager *et al.*, 2008). Soil degradation is caused by unsustainable land uses and management practices, and climate extremes (FAO, 2015). Approximately 50% of potentially arable land in Africa is currently under cultivation, of which 2000 million ha (23% of agricultural land) are already of low soil fertility, and the soil fertility of the remaining arable lands continues to decline due to mismanagement (FAO, 2003; UNEP, 2004). According to FAO (2015) estimation, about 83% of rural people in Sub-Saharan Africa depend on the land for their livelihoods, but 40% of Africa's land resources are currently degraded. Furthermore, about 33% of soils are moderately to highly degraded due to erosion, nutrient depletion, acidification, salinisation, compaction and chemical pollution (FAO, 2015). The decline in soil fertility is especially severe in tropical soils. Monocropping, nutrient mining, unbalanced nutrient application, removal of crop residues from the fields and inadequate re-supplies of nutrients have contributed to decline in crop yields (Nyamangara, 2001).

Soil degradation is also process that describes human-induced phenomena, which lowers the current and/or future capacity of the soil to support human life (ISRIC, 1990). The ever-increasing human population is most challenging in developing countries because of soil degradation. For instance, in Sub-Saharan African countries, soil fertility depletion is the fundamental biophysical cause for declining per capital food production (Sanchez *et al.*, 1997). The population of Ethiopia is currently growing at a faster rate and demands an increasing proportion of agricultural products. On the other hand, growth in food production is not in equal footings with population pressure. This challenge will continue as population pressure increases and degradation of soil resources is aggravated. The rate of soil quality degradation depends on land use systems, soil types, topography, and climatic conditions. Several works showed that inappropriate land use aggravates the degradation of soil physicochemical and biological properties (Saikhe *et al.*, 1998; He *et al.*, 1999). Maddonni *et al.* (1999) also reported that land use affects basic processes such as erosion, nutrient cycling, leaching and other similar physical and biochemical processes.

Soil acidity is one of the main factors that limit and prevent profitable and sustained agricultural

productivity in many parts of the world (Sumner and Noble, 2003). It is estimated that approximately 50% of the worlds' arable soils are acidic and may be subjected to the effect of aluminum (Al) toxicity of which the tropics and subtropics account for 60% of the acid soils in the world (Sumner and Noble, 2003). The extent of soil acidity in Africa is difficult to quantify. Eswaran *et al.* (1997) estimated that 28.8% of the African continent has acid surface soils and 19.6% has sub soil acidity problems. In the tropics the soil acidity is aggravated by leaching or/and continuous removal of basic cations through crop harvest. About 40.9% of the Ethiopian total land is affected by soil acidity. Of this area, about 27.7 % are dominated by moderate to weak acid soils (pH in KCl of 4.5 -5.5), and around 13.2 % are strong acid soils (pH in KCl of <4.5 and nearly one-third have aluminum toxicity problem (Mesfin, 2007). In humid and sub-humid area of Ethiopia, vast areas of land in the western, south-western, north-western and even the central highlands of the country which receive high rainfall are thought to be affected by soil acidity (Mesfin, 2007) attributed to various factors including continuous cropping (in many areas mono-cropping) without the use of the required inputs, the problem of soil acidity in the country is apparently increasing recently both in area coverage and severity of the problem. The major soil forming factors and management practices giving rise to the increase in soil acidity in the country involve climatic factors such as RF/temp, topographic factors, soil parent materials, intensive mono-cropping and lack of technological inputs in the peasant sector to mitigate the problem (Mesfin, 1998).

Soil acidity affects the growth of crops because acidic soil contain toxic levels of aluminum and manganese and characterized by deficiency of essential plant nutrients such as P, N, K, Ca, Mg, and Mo (Wang *et al.*, 2006). At pH below five (5), aluminum is soluble in water and becomes the domination in the soil solution. In acid soils, excess aluminum primarily injures the root apex and inhibits root elongation (Sivaguru and Horst, 1998). The poor root growth leads to reduced water and nutrient uptake, and consequently crops grown on acid soils are confronted with poor nutrients and water availability. The negative effect of high levels of soluble aluminum on plants growth has been widely reported (Matsumoto, 2002; Langer *et al.*, 2009). The net effect of which is reduced growth and yield of crops (Wang *et al.*, 2006 ).

According to Angaw and Desta (1988), soil acidity severely affects the yields of many crops in the western, south-western and southern parts of high rainfall areas of Ethiopia. In these areas, the annual rainfall exceeds the potential evaporation. Leaching of cations in soils is most responsible for increased soil acidity (Schlede, 1989). The infertility of soils in these areas is attributed to excessive concentration of aluminum (Al), iron (Fe) or manganese (Mn) on one hand; and to deficiencies of calcium (Ca), magnesium (Mg), phosphorus (P) and molybdenum (Mo) on the other (Mesfin, 1996). Soil fertility and its potential productivity are closely related to soil physicochemical properties, among which soil reaction (soil pH) has the greatest share. As to the nature and deleterious effects of soil acidity, Al, Fe, and Mn become more soluble and hence their concentration on the exchange complex increases (Mesfin, 1996). The chemistry of these toxic elements in the soil is complex and affects the nutrient balance in soil solution. Among the soil chemical properties, available soil phosphorus, cation exchange capacity (CEC), exchangeable bases and available micronutrients are the most affected by soil acidity. To increase crop yields and reduce crop production risks associated with soil acidity, there is need to focus on soil amendment practices that target efficiency of nutrients use in soils especially phosphorus that is made unavailable chemically for plant uptake.

The agronomic and management options to correct acid soils, improve nutrient use efficiency, and increase crop production on acidic soils include liming, application of organic materials, appropriate crop rotations and use of plant species and varieties tolerant to Al and Mn toxicity (Sanchez and Salinas, 1981). Liming acid soils is a general practice to reduce aluminum toxicity and is considered to many scientists as the first step towards providing a balanced nutrition for cultivated plants (Brown and Stecker, 2003; Essington, 2004). Therefore the objective of this paper is to review the extent of acid soil distributions in Ethiopia, its impact on crop production and management practices.

## 2. METHODOLOGY OF REVIEW

To the success of this work, different sources such as journals, proceedings, thesis works and reports related to the extent of acid soil in Ethiopia, its impact on crop production and management methods have been used.

## 3. THE EXTENT OF ACID SOIL IN ETHIOPIA, ITS IMPACT CROP PRODUCTION AND MANAGEMENT METHODS

### 3.1. The Extent of Soil Acidity in Ethiopia and Its Causes

Soil acidity is a serious agricultural and environmental problem that limits the growth of pasture and crops in many parts of the world including Latin America, North America, Asia, Africa, Europe and Australia (Baligar *et al.*, 1993). Yang *et al.* (2012) stated that approximately 43% of the world's tropical land area is classified as acidic, comprising of about 68% of tropical America, 38% of tropical Asia, and 27% of tropical Africa. Acidic soils cover a total of 1.66 billion hectares (ha) in 48 developing countries, while the total area affected by soil acidity is about 4 billion hectare (Von Uexkull and Mutert, 1995). Tropical and sub-tropical regions as well as

areas with moderate climatic conditions are mostly affected by soil acidity.

According to Schlegel (1989), acid soils are spreading and occupying larger area of cultivated land in Ethiopia. Different reports have indicated that there is significant soil acidity coverage in Ethiopia (World Bank, 1995; Wassie and Shiferaw, 2009). Soil acidity is estimated that about 40.9% of the total arable land of Ethiopia is affected by soil acidity (Abdenna *et al.*, 2007) which covers 95% of the cropped area and contain almost 85% of the Ethiopian population.

The total area of Ethiopia is 111.8 million hectare out of these only 79 million of hectare is suitable for agriculture. Of this soil, about 27.7% are dominated by moderate to weak acid soils (pH in KCl of 4.5 -5.5), and around 13.2 % are strong acid soils (pH in KCl of <4.5 and nearly one-third have aluminum toxicity problem (Mesfin, 2007).

The problem is especially significant in the northwestern, western, southern and central regions of the country. Western and southern parts of Ethiopia, are dominantly covered by soils with pH<5.5 (Schlegel, 1989). However, moderately acidic soils (pH 5.5- 6.5) are distributed through much of the rest of the country (Taye, 2007). In these areas, the annual rainfall exceeds the potential evaporation. Leaching of cations in soils is most responsible for increased soil acidity (Schlegel, 1989). According to Ethio SIS, (2014) about 43% of the Ethiopian arable land is affected by soil acidity of these about 28.1% of soils in Ethiopia are dominated by strong acid soils (pH 4.1-5.5) (Figure 1). Strongly acidic soils are usually infertile because of the possible Al and Mn toxicities, and Ca, Mg, P, and molybdenum (Mo) deficiencies (Barber, 1984).

In Ethiopia, soil acidity increase involves climatic factors, such as rainfall, temperature, and topographic factors. Soil acidity in Ethiopia often developed in regions where excessive rainfall coupled with unfavorable temperature and precipitation is high enough to leach appreciable amounts of exchangeable basic ions like calcium (Ca), magnesium (Mg), sodium (Na) and potassium (K) from the surface of soils (Mesfin 2007). Its severity is extremely variable due to the effects of parent materials, land form, vegetation and climate pattern (Achalu *et al.*, 2012).

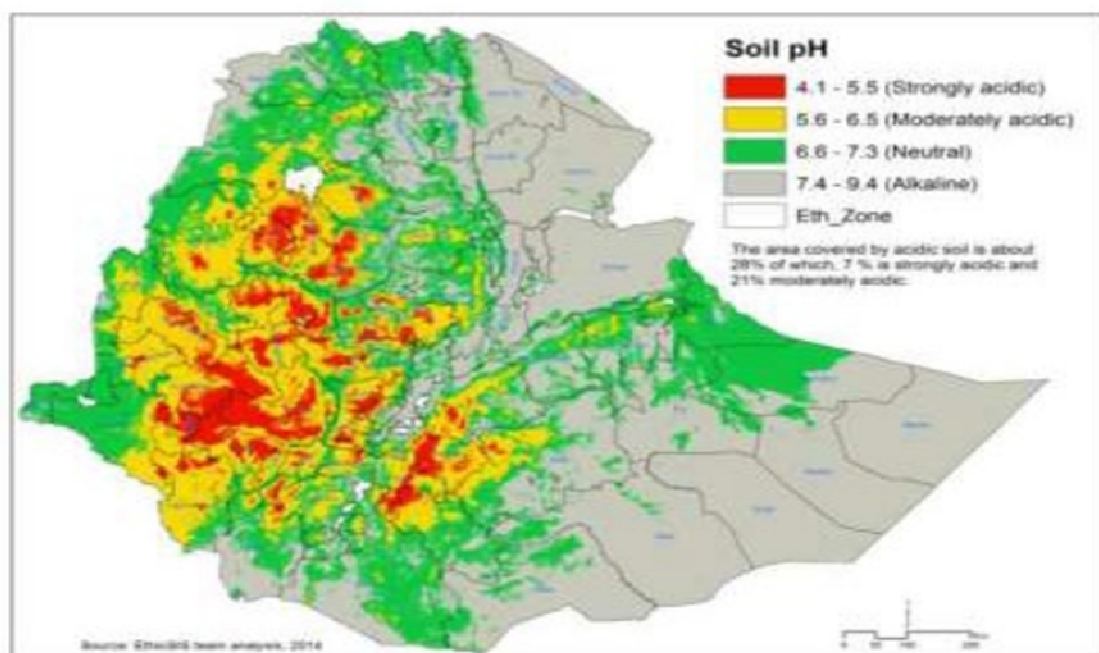


Figure 1. Extent and Distribution of Soil Acidity in Ethiopia (Ethio SIS, 2014)

### 3.2. Impacts of Soil Acidity on Crop Production

Acidity produces complex interactions of plant growth - limiting factors involving physical, chemical, and biological properties of soil (Robarge, 2008). Soil erosion and low water - holding capacity are major physical constraints for growing crops on tropical soils. Calcium, magnesium, and phosphorous deficiencies or unavailabilities and aluminum toxicity are considered major chemical constraints that limit plant growth on acid soils (Menzies, 2003). Among biological properties, activities of beneficial microorganisms are adversely affected by soil acidity, which has profound effects on the decomposition of organic matter, nutrient mineralization, and immobilization, uptake, and utilization by plants, and consequently on crop yields (Fageria, 2009).

The two fundamental factors that limit the fertility of acid soils: i) nutrient deficiencies, e.g. phosphorus (P), calcium (Ca) and magnesium (Mg) and ii) the presence of phytotoxicity substances, e.g. soluble aluminium (Al) and manganese (Mn) (Mesfin, 2007). Aluminium (Al) in acid soil will be solubilized into ionic forms, especially when the soil pH falls to lower than five (5). These ionic forms of Al have been shown to be very toxic to plants, initially causing inhibition of root elongation by destroying the cell structure of the root apex and thus affecting water and nutrient uptake by the roots; as a consequence, plant growth and development is seriously hindered (Barber, 2001). On the other hand, phosphorous (P) is easily fixed by clay minerals that are rich in acids soils, including various iron oxides and kaolinite, and hence rendering it unavailable for root uptake (Mesfin, 2007). Thus, Al toxicity and P deficiency are considered to be two main constraints for crop production in acid soil (Barber, 2001).

Soil acidity affects the growth of crops because acidic soil contain toxic levels of aluminum and manganese and characterized by deficiency of essential plant nutrients such as P,N, K, Ca, Mg, and Mo (Wang *et al.*, 2006). At pH below five (5), aluminum is soluble in water and becomes the domination in the soil solution. In acid soils, excess aluminum primarily injures the root apex and inhibits root elongation (Sivaguru and Horst, 1998). The poor root growth leads to reduced water and nutrient uptake, and consequently crops grown on acid soils are confronted with poor nutrients and water availability. The net effect of which is reduced growth and yield of crops (Wang *et al.*, 2006). The productivity of acid soils is limited by the presence of toxic levels of Al and Mn and deficiency of nutrients such as P, Ca, Mg and Mo (Brady and Weil, 2014). The solubility and availability of important nutrients to plants is closely related to the pH of the soil (Marschner, 2011).

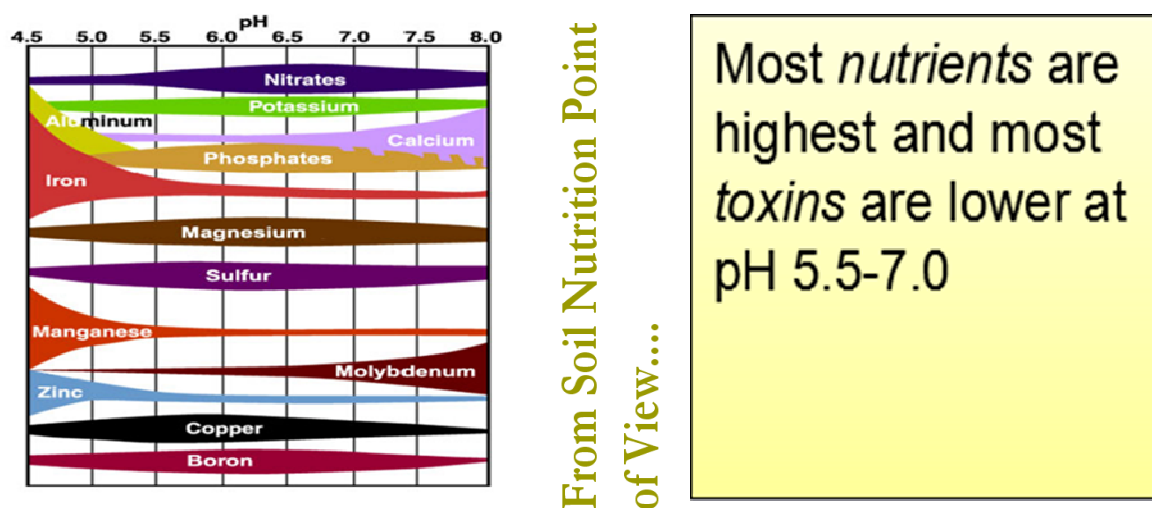


Figure 2. Effect of soil PH on soil nutrient availability

### 3.3. Management Option of Soil Acidity Problems

Major constraints to crop production in tropical acid soils are toxicities of Al and Mn and deficiencies of Ca/Mg (Mesfin, 2007). In order to have successful agriculture in these regions, acid soil stresses need to be alleviated. The agronomic and management options to correct acid soils, improve nutrient use efficiency, and increase crop production on acidic soils include liming, application of organic materials, appropriate and crop mixtures, and use of plant species and varieties tolerant to Al and Mn toxicity (Sanchez and Salinas, 1981).

#### 3.3.1. Liming

Liming of acidic soils to a lower pH neutralize exchangeable  $Al^{3+}$  and  $Mn^{2+}$  toxicity, while supplying Ca and (dolomite lime) magnesium. This generally improves phosphorous uptake by plants (Sanchez and Vehara, 1980). By reducing Al toxicity in acidic soils, liming often increase the effective crop rooting depth, allowing a bigger soil volume to be explored for nutrients and water by the crop (Fageria and Baligar, 2008). Number of liming materials includes crushed limestone ( $CaCO_3$ ), dolomatic lime ( $CaMgCO_3$ ), Slaked lime ( $Ca(OH)_2$ ), quick lime ( $CaO$ ) etc., can be used to minimize soil acidity. Studies have shown that apart from reducing the acidity of the soil by counter acting the effects of excess  $H^+$  and  $Al^{3+}$  ions (Fageria and Baligar, 2003), according to this author, liming also has several other benefits including, its ability to reduce the toxicity effects of some microelements by lowering their concentrations while increasing the availability of plant nutrients such as Ca, P, Mo, and Mg in the soil and reducing the solubility of heavy metals. Crops absorb most of these nutrient elements particularly Ca, P, and Mg in substantial amounts and therefore by increasing their amounts in soil, crop yields can be significantly improved. Liming also stimulates microbial activity and enhances N fixation and N mineralization and hence, legumes are highly benefited from liming (Fageria and Baligar, 2008). Therefore, Liming is a major and effective practice to overcome soil acidity constraints and improve crop production on acid soils. Lime is



called the foundation of crop production or “workhorse” in acid soils (Fageria and Baligar, 2008).

### 3.3.1.1. Potential effects of lime on some chemical properties of acid soils and grain yield

#### 3.3.1.1.1. Soil reaction (pH)

Soil reaction is expressed in terms of pH indicating whether the soil is acidic, alkaline or neutral. Soil pH measures the molar activity (concentration) of hydrogen ions in the soil solution. The solubility and availability of important nutrients to plants is closely related to the pH of the soil (Marschner, 2011). By increasing soil pH, liming makes other nutrients more available, and prevents Al and Mn from being toxic to plant growth (Yao *et al.*, 2010).

According to the study conducted by Buni (2014) soil pH increased from 5.03 to 6.72 due to the application of 3.75 t ha<sup>-1</sup> lime (Table 1). Another study conducted by Moges *et al.* (2018) shows that Application of lime and P fertilizer brought a change on pH. The mineral P fertilizer application has no effect on the pH compared to the control. Similarly, Dessalegn *et al.* (2018) found that soil pH increased due to the application to different lime as compared to control (Table 1). The rise in pH and reduction of soil exchangeable acidity is associated with the presence of basic cations (Ca<sup>2+</sup> and Mg<sup>2+</sup>) and anions (CO<sub>3</sub><sup>2-</sup>) in lime that are able to exchange H<sup>+</sup> from exchange sites to form H<sub>2</sub>O + CO<sub>2</sub>. Cations occupy the space left behind by H<sup>+</sup> on the exchange leading to the rise in pH (Fageria *et al.*, 2007). Kisinyo *et al.* (2012) also reported that soil pH increase in lime treatment as a result of H<sup>+</sup> and Al<sup>3+</sup> ions displacement from soil adsorption sites by Ca<sup>2+</sup> ions contained in lime. Liming of acid soils raises soil pH, which in turn releases phosphate ions precipitated with Al and Fe ions thus making P available for plant uptake (Achalal *et al.*, 2012).

#### 3.3.1.1.2. Exchangeable acidity

Exchangeable acidity consists of aluminum or iron, as well as any exchangeable H that may be present in the exchange sites (Bohn *et al.*, 2001). Exchangeable acidity in soils is almost entirely due to Al<sup>3+</sup> ions. This is because only Al<sup>3+</sup> is a common exchangeable cation in moderately to strongly acidic soils (Bohn *et al.*, 2001).

Exchangeable Al normally occurs in significant amounts only at soil pH values less than about 5.5. As the pH of the soil solution increases, first one and then two of the (OH<sub>2</sub>)<sup>+</sup> groups lose a hydrogen ion to form an (OH)<sup>+</sup> ion, resulting in di- or monovalent hydroxyl-aluminum cations. All three of these cation species are adsorbed by negatively charged exchange sites and thus reduce the cation exchange capacity (CEC) of soil (Bohn *et al.*, 2001). The fraction of exchange sites occupied by Al (H<sub>2</sub>O)<sub>6</sub><sup>3+</sup> and its hydrolysis products can become large once the soil pH falls below 5.5. Furthermore, as the pH is lowered, the concentration of soluble aluminum, which is toxic, increases (McBride, 1994). In addition to direct toxic effects of soluble Al<sup>3+</sup> to plants, it replaces the plant nutrient cations such as Ca and Mg, and simultaneously acts as strong absorber of phosphate (Marschner, 2002). Liming soils to reduce toxic levels of Al is recognized as necessary for optimal crop production on acid soils.

The experiment conducted by Buni (2014) shows that exchangeable acidity (EA) was significantly reduced due to the application of lime on Nitisol with an inherent property of high P fixation (Table 1). This decrease may be ascribed to the increased replacement of Al by Ca in the exchange site and by the subsequent precipitation of Al as Al (OH)<sub>3</sub>, as the soil was limed (Havlin *et al.*, 1999). Moreover, an increase in soil pH results in precipitation of exchangeable and soluble Al as insoluble Al hydroxides thus reducing concentration of Al in soil solution. Moges *et al.* (2018) also shows that Application of lime and P fertilizer brought a change on exchangeable acidity. The mineral P fertilizer application has no effect on exchangeable acidity compared to the control (Table 1). Effiong and Okon (2009) also reported that treated acidic soils with various liming materials for one month generally reduced exchangeable acidity among which CaCO<sub>3</sub> used as a liming material showed up to 68% reduction of exchangeable acidity of the soils. Another study conducted by Dessalegn *et al.* (2018) also shows application of different splits of lime significantly reduced exchangeable acidity to the minimum level. Application of lime, irrespective of the rate used, significantly reduced the exchangeable acidity compared to the control (Table 1). This is to be expected because lime is known to increase the soil pH, hence precipitating Al as Al(OH)<sub>3</sub> (Hue, 2004).

#### 3.3.1.1.3. Available phosphorus

Phosphorus deficiency problems are compounded by widespread high phosphorus fixation capacity of acid soils (Somani, 1996). Since elemental P is very reactive chemically; it is not present in the pure state in nature. It is found only in chemical combinations with other elements (Gupta, 2000). The extent of inorganic P fixation depends on many factors, most importantly soil pH. In acidic soils, inorganic P precipitates as Fe/Al-P secondary minerals and/or is adsorbed to the surfaces of Fe/Al oxides and clay minerals (Havlin *et al.*, 1999). Cheng *et al.* (1999) observed that up to 98% of applied phosphate was converted into unavailable forms in acid soils within very short periods. Application of lime to acidic soils is generally credited for increasing the availability of P.

The experiment conducted by Buni (2014) shows that liming significantly increased available P (Table 1). Similarly, Moges *et al.* (2018) also shows that Application of lime and P fertilizer brought a change on available P (Table 1). Liming of acid soils raises soil pH, which in turn releases phosphate ions precipitated with Al and Fe ions thus making P available for plant uptake (Achalal Chimdi *et al.*, 2012).

### 3.3.1.1.4. Cation exchangeable capacity

The cation exchange capacity (CEC) of a soil represents the total quantity of negative charge available to attract cations in the soil solution. It is one of the most important chemical properties of soils as it strongly influences nutrient availability (Havlin *et al.*, 1999). The CEC of highly weathered soils is pH dependant, and it is a function of the constituent minerals and organic matter. Under such soil, the CEC is increased as the pH of the soil increased by liming.

According to study conducted by Buni (2014) the highest and the lowest values of CEC were observed under the highest lime treated and the control plots, respectively (Table 1). The increase in CEC due to liming could be attributed to the change in pH and reduction of exchangeable acidity which in turn increased the exchange sites of the soil. Generally liming raises soil pH, base saturation and reduces  $Al^{3+}$  concentration.

Table 1. Potential effects of lime on some chemical properties of acid soils

Treatments (Lime t ha <sup>-1</sup> )	pH (H <sub>2</sub> O)	EA(mg kg <sup>-1</sup> )	P (mg kg <sup>-1</sup> )	CEC(Cmol(+) kg <sup>-1</sup> )	Study site	Auther(s)
Control	5.03 <sup>d</sup>	0.97 <sup>a</sup>	5.36 <sup>b</sup>	19.18 <sup>d</sup>	Southern Ethiopia	Buni, 2014
1.25	5.64 <sup>c</sup>	0.75 <sup>b</sup>	6.70 <sup>a</sup>	25.21 <sup>c</sup>		
2.50	6.14 <sup>b</sup>	0.51 <sup>c</sup>	7.04 <sup>a</sup>	31.49 <sup>b</sup>		
3.75	6.72 <sup>a</sup>	0.36 <sup>c</sup>	6.67 <sup>a</sup>	33.34 <sup>a</sup>		
LSD(0.05)	0.014	0.21	0.94	0.738		
CV(%)	3.01	6.43	2.04	6.24		
Control	5.04	0.96	8.95	18.76	North shewa Zone, Amhara	Moges <i>et al.</i> , 2018
4 tone lime	5.51	0.35	15.66	17.29		
6 tone lime	5.64	0.19	16.77	17.11		
20 kg P	5.07	0.89	19.38	18.96		
20/4 P lime	5.59	0.18	20.05	18.02		
20/6 P lime	5.86	0.14	26.94	17.21		
30 kg P	5.09	0.78	22.34	18.67		
30/4 P lime	5.44	0.32	28.34	17.09		
30/6 P lime	5.79	0.16	30.43	16.84		
40 kg P	5.11	0.74	24.62	18.82		
40/4 P lime	5.49	0.25	29.23	17.26		
40/6 P lime	5.72	0.18	31.9	17.08		
Mean	5.45	0.43	23.24	17.76		
Control	5.0b	1.4a	2.2c		Asosa	Dessalegn Temane <i>et al.</i> , 2018
Full dose of lime	5.7a	0.8b	2.8 bc			
50% lime each year	5.9a	0.4c	3.2b			
33% lime each year	5.8a	0.6bc	2.9bc			
25% lime each year	5.8a	0.7bc	4.2a			
LSD(0.05)	0.4	0.4	0.9			
CV(%)	5.82	39.3	24.5			

Soil pH; Ex.Ac, exchangeable acidity; Av.P, available P; CEC, cation exchange capacity.

### 3.3.1.1.5. Exchangeable bases (Ca, Mg, K and Na)

The most common cations associated with CEC are  $Al^{3+}$ ,  $H^+$ ,  $Ca^{2+}$ ,  $Mg^{2+}$ ,  $K^+$ ,  $NH_4^+$  and  $Na^+$ . Except  $Al^{3+}$ , most of the exchangeable cations are plant nutrients. The removal of base cations, especially Ca and Mg, by leaching and erosion results in their replacement by acidic cations like H, Al and Fe on exchange sites and in the soil solution (Johnston, 2004).

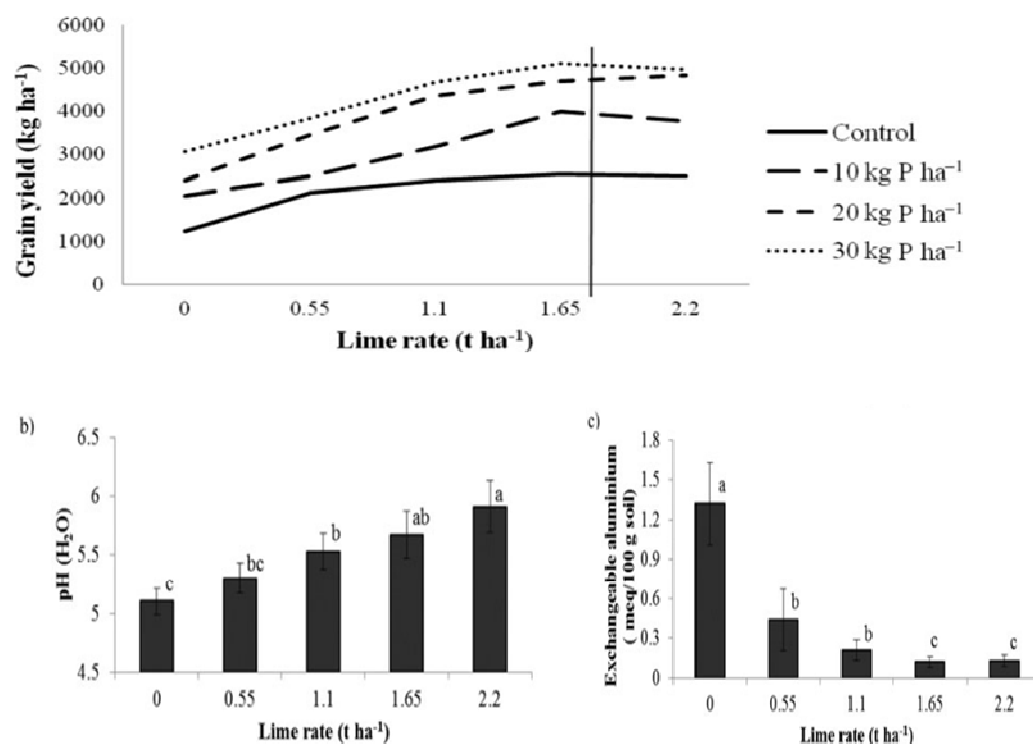
Tigist (2017) found an increase in exchangeable bases (Ca, Mg, K and Na) with an increasing lime rates when compared with contrlrol (Table 2). Similarly Abdissa (2018) also reported that increased soil exchangeable bases as a result of lime application might be attributed to increase in soil pH which in turn may have increased exchangeable bases availability in the soil (Table 2). The results are in agreement with Andric *et al.* (2012) who reported that soil exchangeable bases increased when acidic soil was amended by lime and manure.

Table 2. Effect of limes on soil exchangeable base

Treatment	Exchangeable bases (cmol(+) kg <sup>-1</sup> )				Study site	Author(s)
	Ca	Mg	K	Na		
Control	4.80	0.84	0.74	0.10	Asosa	Yigist, 2017
1.62 t ha <sup>-1</sup> Lime	5.20	3.10	1.18	0.30		
3.26 t ha <sup>-1</sup> Lime	5.20	3.59	1.18	0.26		
4.90 t ha <sup>-1</sup> Lime	6.24	3.94	1.18	0.17		
Control	3.5	1.52	0.25	0.16	East wollega	Abdissa Bekele, 2018
2 t ha <sup>-1</sup> Lime	4.5	1.65	0.31	0.78		
4 t ha <sup>-1</sup> Lime	5.2	1.88	0.41	0.90		
6 t ha <sup>-1</sup> Lime	5.9	3.09	0.42	0.97		

### 3.3.1.1.6. Grain yield

According to Desalegn *et al.* (2017) the combined application of 1.65 t lime ha<sup>-1</sup> and 30 kg P ha<sup>-1</sup> resulted in 133% more grain yields of barley than the control (without P and lime) (Figure 3 a). Application of 0.55, 1.1, 1.65 and 2.2 t lime ha<sup>-1</sup> decreased Al<sup>3+</sup> by 0.88, 1.11, 1.20 and 1.19 mill equivalents per 100 g of soil, and increased soil pH by 0.48, 0.71, 0.85 and 1.1 units, respectively (Figure 3 b,c). Similarly Mahler *et al.* (1988) reported that yields of pea could be increased by 30% due to lime application to soils. Yield increments showed direct relationship with the soil pH values and inverse relationship with exchangeable acidity, i.e. as the pH increased the yield also increased, but as the exchangeable acidity decreased the yield increased and vice versa.



Source: Temesgen Desalegn *et al.*, 2017

Figure 3. Barley grain yield: Interaction between rate of lime and rate of P applied.

Another experiment conducted by Dessalegn *et al.* (2018) on split application of lime also indicates that combined over three years grain yield of soybean recorded from control was significantly lower than the other treatments (Table 3). The highest grain yield of soybean obtained by application of 25% of split application of lime gives comparable yield with full dose of lime and 50% of split applied lime. Therefore, from this result, we generalize that split application of lime could give relatively comparable yield when compared with full dose application and could be a good option for poor small holder farmers.

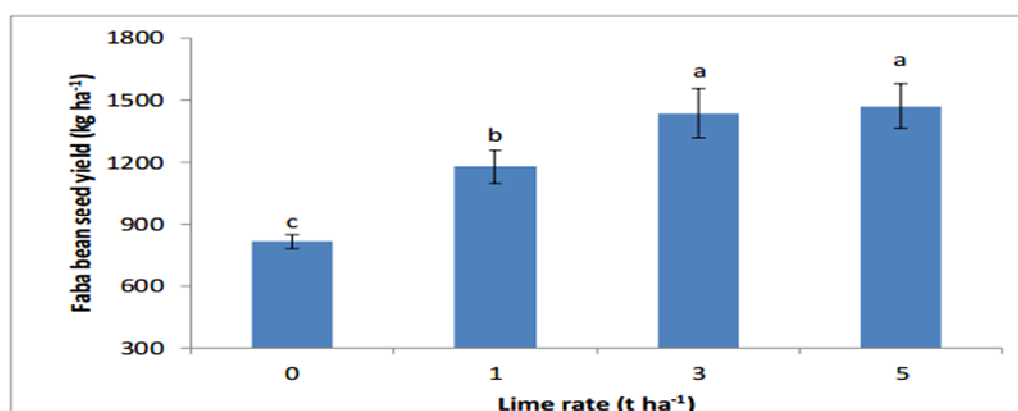
Table 3. Soybean seeds per yield and grain yield as influenced by split application of lime

Treatments	SPP	GY(kg ha <sup>-1</sup> )
Control	2.3b	701.3c
Full dose of lime	2.8ab	1031.6ab
50% lime each year	3.2a	1178.0a
33% lime each year	2.9a	926.1b
25% lime each year	2.9a	975.5ab
LSD(0.05)	0.54	216.7
CV(%)	20.2	23.5

SPP = seed per pod, GY= Grain Yield

Source: Dessalegn Tamene *et al.*, 2018

Similary, Agegnehu *et al.* (2006) reported that the application of lime at the rates of 1, 3 and 5 t ha<sup>-1</sup> resulted significantly in linear response with mean faba bean seed yield advantages of 45, 77 and 81% over the control (Figure 4). Generally, this might be with successive increase in the amounts of lime, grain yields increases with increase in soil pH and corresponding decrease in exchangeable Al<sup>3+</sup> of the soil.



LSD at 5% = 192, Error bars represent  $\pm 1$  SE. Source: Agegnehu *et al.* (2006)

Figure 4. Effects of lime application rates on grain yield of faba bean

### 3.3.2. Management of acidic soil using integrated soil fertility management (ISFM)

Integrated soil fertility management (ISFM) is one of the approaches to manage and improve soil health and fertility status ( Agegnehu and Amede, 2017 ). It is one of the components of the management of acid soils. Farmyard manure (FYM) and crop residues are among organic plant nutrient sources, which could ameliorate the physical and chemical properties of soils. For example, Lal (2009) indicated that returning crop residues to soil as amendments is essential for recycling plant nutrients (20–60 kg of N, P, K, Ca per Mg of crop residues) amounting to 118 million Mg of N, P, K in residues produced annually in the world (83.5% of world's fertilizer consumption). In acid soils, where P fixation is a problem application of FYM releases a range of organic acids that can form stable complexes with Al and Fe thereby blocking the P retention sites, and as a result, the availability and use efficiency of P is improved (Agegnehu and Amede, 2017 ).

The addition of organic fertilizers to acid soils has been effective in reducing phytotoxic levels of Al resulting in yield increases. The major mechanisms responsible for these improvements are thought to be the formation of organo-Al complexes that render the Al less toxic or direct neutralization of Al from the increase in pH caused by the organic matter.

The management of acid soils through integrated soil fertility and plant nutrient management not only improve the yields of crops but also the chemical properties of soils. Regular applications of organic residues can induce a long-term increase in SOM and nutrient content. According to Haynes and Mokolobate (2001), complexation of Al by the newly-formed organic matter tends to reduce the concentrations of exchangeable and soluble Al. As organic residues decompose, P is released and can be adsorbed to oxide surfaces. This can reduce the extent of adsorption of subsequently added P thus increasing P availability. The possible alternative of using organic sources such as crop residues, manures, compost and biochar are substitutes for lime (Sharma *et al.*, 1990; Agegnehu and Amede, 2017).

The practical implication of these processes is that organic residues may be used as a strategic tool to reduce the rates of lime and fertilizer P required for optimum crop production on acidic, P-fixing soils.

The experiment conducted by Getachew and Chilot (2003) found that soil pH has been improved through FYM application. The analysis of soil samples indicated relatively higher pH levels and nutrient concentrations for plots treated with both FYM and P fertilizer compared to either sole application of FYM or P fertilizer (Table



4). Similarly, Ano and Ubochi (2007) reported that application of animal manure increased soil pH. The lowest pH and nutrient content were observed on plots not treated with FYM. The result also shows that the interaction of farmyard manure by phosphorus fertilizer increased faba bean grain yield. The mean grain yields of faba bean increased as the levels of the two interacting factors increased (Table 4).

Similarly, another experiment conducted by Agegnehu *et al.* (2014) also showed that the application of different soil fertility management treatments affected organic carbon, total N, available P. Also applications of inorganic and organic nutrient sources either alone or in combination had a significant effect on grain yield (Table 4). The results of this study clearly clarify that if the application rate of fertilizers either as inorganic, organic or the combination of both is at least doubled under farmers' field condition the yield gain will be more than double compared to the control plot and more than 50% compared to the farmers' applied rate.

In general, integrated use of organic and inorganic nutrient sources could result in significant improvement in the overall condition of the soil as well as agricultural productivity if adopted by producers in the area.

Table 4. Response of ISFM to Grain yield and selected soil physico chemical properties

Table 4. Response of FBN to Grain yield and selected soil physico chemical properties							Author(s)
Treatment		pH	P(ppm)	OC(%)	CEC	Grain yield	
FYM (t ha <sup>-1</sup> )	P applied (kg ha <sup>-1</sup> )	(H <sub>2</sub> O)			(Meq/100g soil )	of Faba bean (kg ha <sup>-1</sup> )	
0	0	4.5	4.2	1.28	18.76	991	Getachew and Chilot, 2003
0	13	4.6	4.4	1.29	18.84	1412	
0	26	4.7	5.2	1.29	19.08	1317	
0	39	4.6	5.2	1.30	19.22	1467	
0	52	4.6	5.4	1.29	19.14	1573	
4	0	4.7	4.6	1.32	20.54	1395	
4	13	4.7	5.4	1.36	20.12	1701	
4	26	4.7	5.4	1.36	20.74	1954	
4	39	4.8	5.6	1.36	21.24	1958	
4	52	4.8	6.4	1.36	21.38	2007	
8	0	4.6	5.2	1.40	21.26	1981	
8	13	4.9	6.0	1.48	22.38	1942	
8	26	4.7	6.4	1.44	24.28	2019	
8	39	4.8	6.0	1.44	23.50	2210	
8	52	4.9	6.4	1.44	25.64	2191	
Mean		4.84	5.45	1.36	21.08	SE= 58.68	
Wheat							Agegnehu <i>et al.</i> , 2014
Control		5.57	9.40	1.36		1258e	
Farmers NPK rate (23/10/0)		5.36	11.00	1.61		1713d	
Recommended NP K(60/20/0)		5.26	15.55	1.83		3164a	
50% of recommended NPK + 50% manure + 50% compost as N equivalence (3.25 t/ha)		5.76	15.57	2.06		2882b	
50% Manure +50% compost as N equivalence (6.5t/ha)		6.15	15.52	1.98		2646c	
LSD(0.05)		0.39	0.02	3.40		228.58	
CV (%)		4.55	2.69	16.40		9.35	

### 3.3.3. Management of acid soils using acid tolerant crop varieties

Over the past decade, several researchers around the world have focused their efforts on identifying and characterizing the mechanisms employed by crop plants that enable them to tolerate Al toxic levels in acid soils. The two distinct classes of Al tolerance mechanisms are those that operate to exclude Al from the root apex and those that allow the plant to tolerate Al accumulation in the root and shoot symplasm (Kochian *et al.*, 2004). A substantial number of plant species of economic importance are generally regarded as tolerant to acid soil conditions. Many of them have their center of origin in acid soil regions, suggesting that adaptation to soil constraints is part of the evolutionary process (Somani, 1996). Although the species as a whole does not tolerate, some varieties of certain species also possess acid soil tolerance.

In the highlands of Ethiopia, barley is mainly grown on Nitisols, where soil pH is low. This means that barley has been already adapted to acid soil conditions. With this understanding five released barley varieties were evaluated under limed and unlimed condition on acidic soils (Getachew *et al.*, 2019). Barley varieties (HB-42 and Dimtu) performed well under limed condition, i.e. yield increments of 366 and 327%, respectively over the corresponding yields of the same barley varieties under unlimed condition were recorded. In contrast, barley varieties (HB-1307 and Ardu) performed better under unlimed condition, i.e. lower yields of 48 and 49%

compared to the corresponding yields of the same barley varieties achieved under limed condition (Table 5).

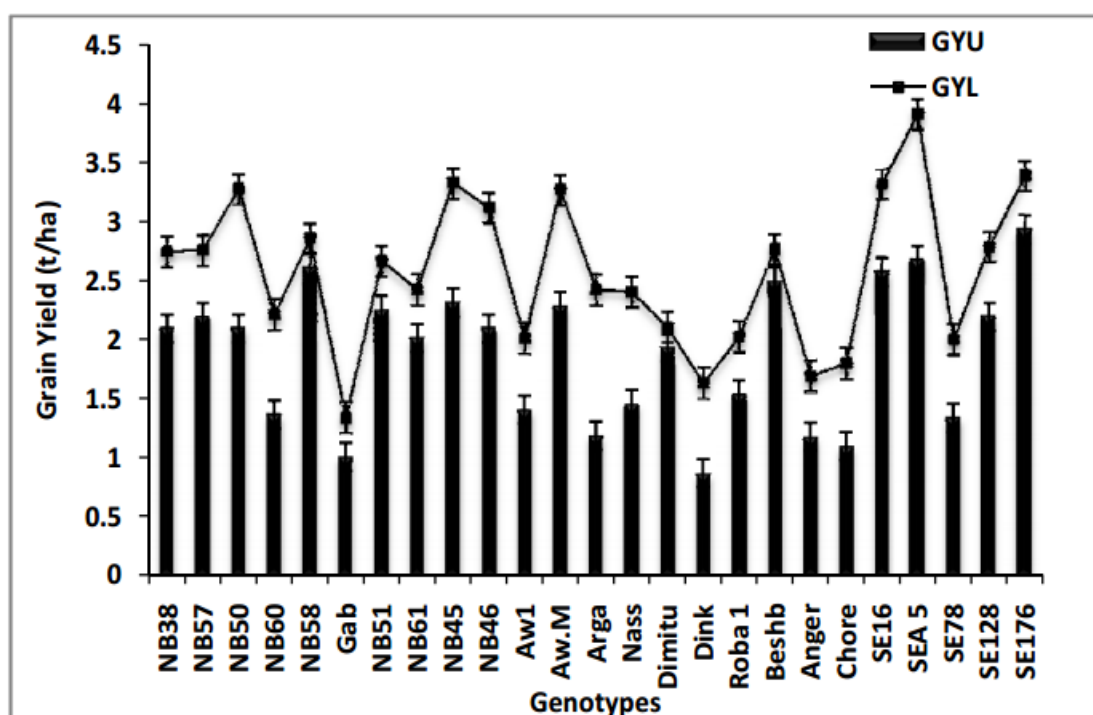
Another study conducted by Hirpa *et al.*(2013) reported that soil acidity had significant effect on yield and yield components of common bean genotypes. On average, the genotypes gave higher yield and biomass yield in lime treated soil for all genotypes over no lime application. The magnitude of increase in grain yield and total dry biomass yield due to liming was 25.7 and 27.6%, respectively over the no lime treatment (Table 5).

Table 5. Performance of different genotypes varieties under limed and un-limed conditions

Variety	Grain yield(kg/ha)		Yield increment (%)	Kind of genotypes	Study site	Author(s)
	Limed	Unlimed				
HB-41	1752	376	366	Barley	Endibir	Getachew Agegnehu <i>etal.</i> ,2019
Shegie	1690	982	72			
Local	1933	1189	63			
HB-1307	2162	1459	48			
Ardu	2020	1355	49			
Dimtu	1818	426	327			
LSD(0.05)	704	1055				
Treatment	GY(t/ha)	BY(t/ha)		Common bean	Nedjo	Hirpa Legesse <i>et al.</i> , 2013
Unlimed	7.4b	3.6b				
Limed	10.3a	5.3a				
CV(%)	9.6	9.5				

Where, GY= grain yield, BY = Biomass yield, t/ha= tonne per hectare CV=coefficient variation.

Hirpa *et al.*(2013) found that higher absolute grain yield in the lime untreated soil was recorded for the genotypes new BILFA 58, SER176, SEA 5, and Beshbesh. However, Gabisa, Chore, and Anger produced the lowest absolute grain yields on the lime untreated soil (Figure 5). Therefore, Soil acidity problems for common bean production can be overcome by growing genotypes which are adapted to acid soil condition in circumstances where other soil amendment strategies are not readily practical (Hirpa *et al.*, 2013). In general the selection of genotypes/varieties adapted to acid soil conditions to could be a good option for many farmers who cannot afford application of liming material.



Source: Hirpa Legesse *et al.*, 2013.

Figure 5. Grain yield of common bean genotypes tested for soil acidity tolerance under lime (L) treated and untreated (U) soil

#### 4. SUMMARY AND CONCLUSION

Soil acidity is a natural process and their formation depends on specific conditions of climate, topography, vegetation, parent material and high rainfall. It is the main factors that limit and prevent profitable and sustained agricultural productivity in many parts of the world including Ethiopia. The objective of this paper is to review

the extent of acid soil distributions in Ethiopia, its impact on crop production and management practices. Currently, it is estimated that about 40.9% of the total arable land of Ethiopia is affected by soil acidity which covers 95% of the cropped area and contain almost 85% of the Ethiopian population. From these 27.7% moderately to weak acids with pH 5.8-6.7 and 13.2% covered by strong to moderate acidic soils with pH less than 5.5. Soil acidity can decrease crop yield. According to Ethio SIS, (2014) about 43% of the Ethiopian arable land is affected by soil acidity of these about 28.1% of soils in Ethiopia are dominated by strong acid soils (pH 4.1-5.5). The detrimental effects of soil acidity normally occur when the soil pH falls below 4.5. The two fundamental factors that limit the fertility of acid soils: deficiencies of phosphorus (P), calcium (Ca) and magnesium (Mg) and phytotoxicity of aluminium (Al). Liming, application of organic materials as ISFM and use of crop varieties tolerant to Al toxicity are the management options to correct acid soils. Liming has ability to reduce the toxicity effects by lowering their concentrations while increasing the availability of plant nutrients such as P, Ca, Mg, and K in the soil and reducing the solubility and leaching of heavy metals. Organic matter application has a liming effect due to its richness in alkaline cations such as Ca, Mg and K, which were liberated from OM due to mineralization. Soil organic matter increase soil pH contribute for soil acidity amendments. Soil acidity problems can be also overcome by growing genotypes which are adapted to acid soil condition in circumstances where other soil amendment strategies are not readily practical. Therefore for sustainable agricultural systems within small-scale farming in Ethiopia, liming, use of integrated soil fertility management, and crop varieties tolerant to Al toxicity are the mechanisms used for management of acid soils and should be demonstrated and popularized on farmers field.

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